## Current

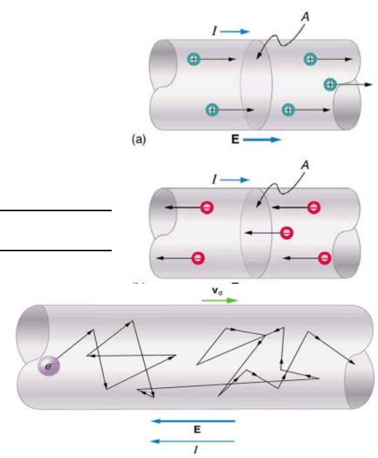
- ____________ of ____________ of ____________
- Amount of ____________ per unit ____________ that crosses one ____________

$$I = \frac{\Delta Q}{\Delta t}$$

- Symbol: (____________)
- Unit: ____________ (A)

Small computer speakers often have power supplies that give 12 VDC at 200 mA. How much charge flows through the circuit in 1 hour and how much energy is used to deliver this charge?

- Electrons are the ____________ that ____________ through ____________
- Historically thought ____________ charges move
- ______________ current is the ____________ flow of ____________ charges
- Flows from ____________ terminal and into ____________ terminal
- ____________ current flows the ____________ way




## Drift Velocity

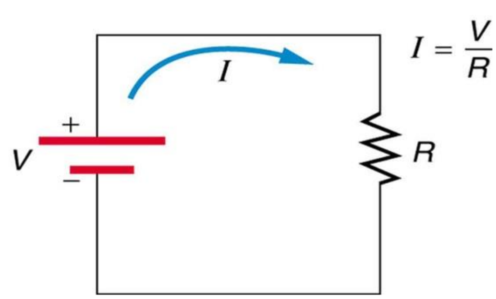
- ____________signals travel near ____________ of ____________, but ____________ travel much ____________
- Each new electron ___________ one ahead of it, so current is actually like ___________

$$I = \frac{\Delta Q}{\Delta t} = qnAv_d$$

  - $q$ = charge of each electron, $n$ = free charge density, $A$ = cross-sectional area, $v_d$ = drift velocity

## Ohm's Law

$$I = \frac{V}{R} \text{ or } V = IR$$




- $V$ = emf, $I$ = current, $R$ = resistance
- Unit: V/A = ____________ (Ω)

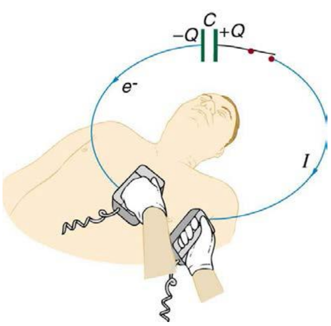
## Resistors

- Device that offers ____________ to ____________ of charges
- ____________ wire has very ____________ resistance
- Symbols used for ____________

Our speakers use 200 mA of current at maximum volume. The voltage is 12V. The current is used to produce a magnet which is used to move the speaker cone. Find the resistance of the electromagnet.

## *Homework*

1. Can a wire carry a current and still be neutral—that is, have a total charge of zero? Explain.
2. Car batteries are rated in ampere-hours (A·h). To what physical quantity do ampere-hours correspond (voltage, charge, …), and what relationship do ampere-hours have to energy content?
3. Why are two conducting paths from a voltage source to an electrical device needed to operate the device?
4. In cars, one battery terminal is connected to the metal body. How does this allow a single wire to supply current to electrical devices rather than two wires?
5. The IR drop across a resistor means that there is a change in potential or voltage across the resistor. Is there any change in current as it passes through a resistor? Explain.
6. What is the current in milliamperes produced by the solar cells of a pocket calculator through which 4.00 C of charge passes in 4.00 h? (OpenStax 20.1) **0.278 mA**
7. A total of 600 C of charge passes through a flashlight in 0.500 h. What is the average current? (OpenStax 20.2) **333 mA**
8. What is the current when a typical static charge of 0.250 μC moves from your finger to a metal doorknob in 1.00 μs? (OpenStax 20.3) **0.250 A**
9. Find the current when 2.00 nC jumps between your comb and hair over a 0.500-μs time interval. (OpenStax 20.4) **4.00 mA**
10. A defibrillator sends a 6.00-A current through the chest of a patient by applying a 10,000-V potential as in the figure below. What is the resistance of the path? (OpenStax 20.7a) **1.67 kΩ**
11. During open-heart surgery, a defibrillator can be used to bring a patient out of cardiac arrest. The resistance of the path is 500 Ω and a 10.0-mA current is needed. What voltage should be applied? (OpenStax 20.8) **5.00 V**
12. (a) A defibrillator passes 12.0 A of current through the torso of a person for 0.0100 s. How much charge moves? (b) How many electrons pass through the wires connected to the patient? (See figure.) (OpenStax 20.9) **0.120 C,** $\mathbf{7.50 \times 10^{17}}$ **electrons**




13. A clock battery wears out after moving 10,000 C of charge through the clock at a rate of 0.500 mA. (a) How long did the clock run? (b) How many electrons per second flowed? (OpenStax 20.10) $\mathbf{2.00 \times 10^{7}}$ **s,** $\mathbf{3.13 \times 10^{15}}$ **electrons/s**
14. What current flows through the bulb of a 3.00-V flashlight when its hot resistance is 3.60 Ω? (OpenStax 20.18) **0.833 A**
15. Calculate the effective resistance of a pocket calculator that has a 1.35-V battery and through which 0.200 mA flows. (OpenStax 20.19) **6.75 kΩ**
16. (a) Find the voltage drop in an extension cord having a 0.0600- Ω resistance and through which 5.00 A is flowing. (b) A cheaper cord utilizes thinner wire and has a resistance of 0.300 Ω. What is the voltage drop in it when 5.00 A flows? (c) Why is the voltage to whatever appliance is being used reduced by this amount? What is the effect on the appliance? (OpenStax 20.22) **0.300 V, 1.50 V**
17. A power transmission line is hung from metal towers with glass insulators having a resistance of 1.00 × 10^9 Ω. What current flows through the insulator if the voltage is 200 kV? (Some high-voltage lines are DC.) (OpenStax 20.23) **0.200 mA**

## *Another way to find resistance*

The ____________ varies ____________ with ____________ and ____________ with ____________ (or cross-sectional ____________) a wire

- Short, thick wire → ____________ resistance
- Long, skinny wire → ____________ resistance

$$R = \frac{\rho L}{A}$$

  - $\rho$ = ____________ (Unit: Ωm)
- Table 20.1 lists resistivities of some materials
  - Metals → ____________ resistivity ($1 \times 10^{-8}\,\Omega\,\mathrm{m}$)
  - Insulators → ____________ resisitivity ($1 \times 10^{15}\,\Omega\,\mathrm{m}$)
  - Semi-conductors → ____________ resistivity

Table 20.1 Resistivities $\rho$ of Various materials at 20ºC

| Material | Resistivity $\rho$ ( $\Omega \cdot m$ ) |
|---|---|
| *Conductors* | |
| Silver | $1.59\times10^{-8}$ |
| Copper | $1.72\times10^{-8}$ |
| Gold | $2.44\times10^{-8}$ |
| Aluminum | $2.65\times10^{-8}$ |
| Tungsten | $5.6\times10^{-8}$ |
| Iron | $9.71\times10^{-8}$ |
| Platinum | $10.6\times10^{-8}$ |
| Steel | $20\times10^{-8}$ |
| Lead | $22\times10^{-8}$ |
| Manganin (Cu, Mn, Ni alloy) | $44\times10^{-8}$ |
| Constantan (Cu, Ni alloy) | $49\times10^{-8}$ |
| Mercury | $96\times10^{-8}$ |
| Nichrome (Ni, Fe, Cr alloy) | $100\times10^{-8}$ |
| *Semiconductors*[1] | |
| Carbon (pure) | $3.5\times10^{5}$ |
| Carbon | $(3.5-60)\times10^{5}$ |
| Germanium (pure) | $600\times10^{-3}$ |
| Germanium | $(1-600)\times10^{-3}$ |
| Silicon (pure) | 2300 |
| Silicon | 0.1–2300 |
| *Insulators* | |
| Amber | $5\times10^{14}$ |
| Glass | $10^{9}-10^{14}$ |
| Lucite | $>10^{13}$ |
| Mica | $10^{11}-10^{15}$ |
| Quartz (fused) | $75\times10^{16}$ |
| Rubber (hard) | $10^{13}-10^{16}$ |
| Sulfur | $10^{15}$ |
| Teflon | $>10^{13}$ |
| Wood | $10^{8}-10^{11}$ |

Why are long wires thick?
Wire thicknesses are measured in gauges. 20-gauge wire is thinner than 16-gauge wire. If 20-gauge wire has $A = 5.2 \times 10^{-7}\ m^2$ and 16-gauge wire has $A = 13 \times 10^{-7}\ m^2$, find the resistance per meter of each if they are copper.

## *Resistivity and Temperature*

$$\rho = \rho_0(1 + \alpha \Delta T)$$

- $\rho$ = resistivity at temperature $T$
- $\rho_0$ = resistivity at temperature $T_0$
- $\alpha$ = temperature coefficient of resistivity (Unit: 1/°C (or 1/K))

Metals

- Resistivity __________ with temperature
- α is ____________

Semiconductors

- Resistivity __________ with temperature
- α is ____________

Table 20.2 Tempature Coefficients of Resistivity $\alpha$

| Material | Coefficient $\alpha$ (1/°C)[2] |
|---|---|
| *Conductors* | |
| Silver | $3.8\times10^{-3}$ |
| Copper | $3.9\times10^{-3}$ |
| Gold | $3.4\times10^{-3}$ |
| Aluminum | $3.9\times10^{-3}$ |
| Tungsten | $4.5\times10^{-3}$ |
| Iron | $5.0\times10^{-3}$ |
| Platinum | $3.93\times10^{-3}$ |
| Lead | $3.9\times10^{-3}$ |
| Manganin (Cu, Mn, Ni alloy) | $0.000\times10^{-3}$ |
| Constantan (Cu, Ni alloy) | $0.002\times10^{-3}$ |
| Mercury | $0.89\times10^{-3}$ |
| Nichrome (Ni, Fe, Cr alloy) | $0.4\times10^{-3}$ |
| *Semiconductors* | |
| Carbon (pure) | $-0.5\times10^{-3}$ |
| Germanium (pure) | $-50\times10^{-3}$ |
| Silicon (pure) | $-70\times10^{-3}$ |

## *Resistance and Temperature*

$$R = R_0(1 + \alpha \Delta T)$$

- $R$ = resistance at temperature T
- $R_0$ = resistance at temperature $T_0$
- $\alpha$ = temperature coefficient of resistivity (Unit: 1/°C (or 1/K))

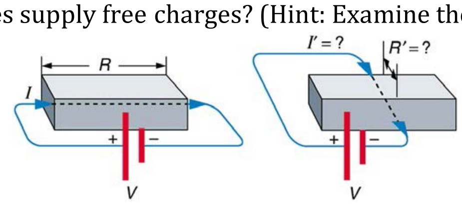
A heating element is a wire with cross-sectional area of $2 \times 10^{-7}\ \mathrm{m}^2$ and is 1.3 m long. The material has resistivity of $4 \times 10^{-5}\ \Omega\mathrm{m}$ at 200°C and a temperature coefficient of $3 \times 10^{-2}$ 1/°C. Find the resistance of the element at 350°C.

## *Superconductors*

- Materials whose _______________ = _______________
- _______________ become superconductors at _______________ _______________ temperatures
    - Some materials using _______________ _______________ work at much _______________ temperatures
- No current _______________
- Used in
    - Transmission of _______________, _______________, _______________, Powerful, small electric motors, Faster _______________ chips

## *Homework*

1. In which of the three semiconducting materials listed in Table 20.1 do impurities supply free charges? (Hint: Examine the range of resistivity for each and determine whether the pure semiconductor has the higher or lower conductivity.)




2. Does the resistance of an object depend on the path current takes through it? Consider, for example, a rectangular bar—is its resistance the same along its length as across its width? (See Figure.)
3. If aluminum and copper wires of the same length have the same resistance, which has the larger diameter? Why?
4. What is the resistance of a 20.0-m-long piece of 12-gauge copper wire having a 2.053-mm diameter? (OpenStax 20.24) **0.104 Ω**
5. The diameter of 0-gauge copper wire is 8.252 mm. Find the resistance of a 1.00-km length of such wire used for power transmission. (OpenStax 20.25) **0.322 Ω**
6. If the 0.100-mm diameter tungsten filament in a light bulb is to have a resistance of 0.200 Ω at 20.0 °C, how long should it be? (OpenStax 20.26) $\mathbf{2.81 \times 10^{-2}\ m}$
7. What current flows through a 2.54-cm-diameter rod of pure silicon that is 20.0 cm long, when $1.00 \times 10^3$ V is applied to it? (Such a rod may be used to make nuclear particle detectors, for example.) (OpenStax 20.28) $\mathbf{1.10 \times 10^{-3}\ A}$
8. (a) To what temperature must you raise a copper wire, originally at 20.0 °C, to double its resistance, neglecting any changes in dimensions? (b) Does this happen in household wiring under ordinary circumstances? (OpenStax 20.29) **276 °C**
9. A resistor made of Nichrome wire is used in an application where its resistance cannot change more than 1.00% from its value at 20.0 °C . Over what temperature range can it be used? (OpenStax 20.30) **−5°C to 45 °C**
10. Of what material is a resistor made if its resistance is 40.0% greater at 100 °C than at 20.0 °C? (OpenStax 20.31) $\mathbf{5.00 \times 10^{-3}\ /°C}$
11. (a) Of what material is a wire made, if it is 25.0 m long with a 0.100 mm diameter and has a resistance of 77.7 Ω at 20.0 °C? (b) What is its resistance at 150 °C? (OpenStax 20.33) $\mathbf{1.1 \times 10^{2}\ \Omega}$
12. (a) Digital medical thermometers determine temperature by measuring the resistance of a semiconductor device called a thermistor (which has α = −0.0600 /°C ) when it is at the same temperature as the patient. What is a patient's temperature if the thermistor's resistance at that temperature is 82.0% of its value at 37.0 °C (normal body temperature)? (OpenStax 20.37a) **40.0 °C**

Physics 09-03 Electric Power and AC/DC Name: ______________________

## *Electric Power*

$P = IV$

- Unit: ____________ (W)
- Other ____________ for electrical ____________

$$P = I^2R$$

$$P = \frac{V^2}{R}$$

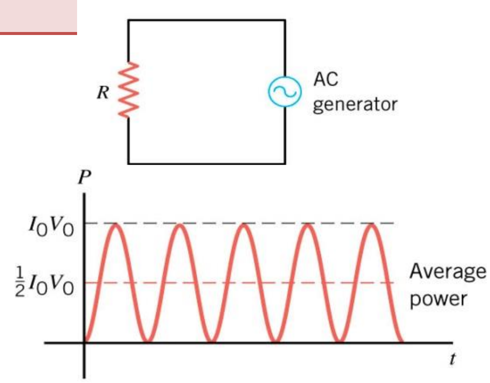
Let's say an electric heater has a resistance of 1430 Ω and operates at 120V. What is the power rating of the heater? How much electrical energy does it use in 24 hours?

## *Kilowatt hours*

- Electrical ____________ ____________ you for the amount of electrical ____________ you use
- Measured in ____________ ____________ (kWh)

If electricity costs $0.15 per kWh how much does it cost to operate the previous heater (P = 10.1 W) for one month?

## *Alternating Current*




- Charge flow ____________ direction __________________
- Due to way that ____________ plants ____________ power
- Simple circuit
- Periodicity
  - __________, __________, and ____________ ____________ with time
  - So we usually talk about the ____________

Average Power

- DC

$$P = IV$$

- AC

$$P_{ave} = \frac{1}{2}I_0V_0$$

  - Often P is used to represent ____________ power in ____________ AC circuits.

Root Mean Square (rms)

$$P_{ave} = \frac{1}{2}I_0V_0 = \left(\frac{I_0}{\sqrt{2}}\right)\left(\frac{V_0}{\sqrt{2}}\right) = I_{rms}V_{rms}$$

- $I_{rms}$ and $V_{rms}$ are called ____________ ____________ ____________ current and voltage
- Found by dividing the ____________ by ____________

$$I_{rms} = \frac{I_0}{\sqrt{2}} \qquad V_{rms} = \frac{V_0}{\sqrt{2}}$$

 Name: ______________________

## *Convention in USA*

- $V_0$ = 170 V, $V_{rms}$ = ____________V
- ____________ electronics specify 120 V, so they really mean ____________
- We will always (unless noted) use ____________ ____________, and root mean square ____________ and ____________
- Thus all ____________ learned equations ____________!

A 60 W light bulb operates on a peak voltage of 156 V. Find the $V_{rms}$, $I_{rms}$, and resistance of the light bulb.

Why are you not supposed to use extension cords for devices that use a lot of power like electric heaters?

## *Homework*

1. Give an example of a use of AC power other than in the household. Similarly, give an example of a use of DC power other than that supplied by batteries.
2. Why do voltage, current, and power go through zero 120 times per second for 60-Hz AC electricity?
3. You are riding in a train, gazing into the distance through its window. As close objects streak by, you notice that the nearby LED christmas lights make dashed streaks. Explain.
4. What is the power of a $1.00 \times 10^2$ MV lightning bolt having a current of $2.00 \times 10^4$ A? (OpenStax 20.40) $\mathbf{2.00 \times 10^{12}}$ **W**
5. What power is supplied to the starter motor of a large truck that draws 250 A of current from a 24.0-V battery hookup? (OpenStax 20.41) **6.00 kW**
6. A charge of 4.00 C of charge passes through a pocket calculator's solar cells in 4.00 h. What is the power output, given the calculator's voltage output is 3.00 V? (OpenStax 20.42) $\mathbf{8.33 \times 10^{-4}}$ **W**
7. How many watts does a flashlight that has $6.00 \times 10^2$ C pass through it in 0.500 h use if its voltage is 3.00 V? (OpenStax 20.43) **1.00 W**
8. Find the power dissipated in each of these extension cords: (a) an extension cord having a 0.0600-Ω resistance and through which 5.00 A is flowing; (b) a cheaper cord utilizing thinner wire and with a resistance of 0.300 Ω. (OpenStax 20.44) **1.50 W, 7.50 W**
9. An electric water heater consumes 5.00 kW for 2.00 h per day. What is the cost of running it for one year if electricity costs 12.0 cents/kW·h? (OpenStax 20.50) **$438/y**
10. With a 1200-W toaster, how much electrical energy is needed to make a slice of toast (cooking time = 1 minute)? At 9.0 cents/kW·h, how much does this cost? (OpenStax 20.51) **0.18 cents**
11. (a) What is the hot resistance of a 25-W light bulb that runs on 120-V AC? (b) If the bulb's operating temperature is 2700°C, what is its resistance at 2600°C? (OpenStax 20.72) **580 Ω, 320 Ω**
12. Certain heavy industrial equipment uses AC power that has a peak voltage of 679 V. What is the rms voltage? (OpenStax 20.73) **480 V**
13. A certain circuit breaker trips when the rms current is 15.0 A. What is the corresponding peak current? (OpenStax 20.74) **21.2 A**
14. What is the peak power consumption of a 120-V AC microwave oven that draws 10.0 A? (OpenStax 20.79) **2.40 kW**
15. What is the peak current through a 500-W room heater that operates on 120-V AC power? (OpenStax 20.80) **5.89 A**

## *Electric Hazards*

Thermal Hazards

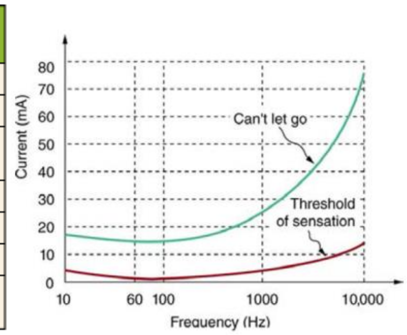
- __________ energy converted to __________ energy __________ than can be __________
- Happens in __________ circuits where electricity __________ between two parts of __________ bypassing the __________ load
  - $P = \frac{V^2}{R}$
  - Low __________ so high __________
  - Can start __________
  - __________ __________ or __________ try to stop
- Or __________ wires that have
  - __________ resistance (__________)
  - Or are __________ so __________ can't __________

Shock Hazards

- Factors
  - __________ of __________
  - __________ of current
  - __________ of shock
  - __________ of current
- Human body mainly __________, so decent __________
- __________ are controlled by __________ impulses in nerves
  - A shock can cause __________ to __________
  - Cause __________ to close around __________ (muscles to close, stronger than to open)
  - Can cause __________ to __________
- Body most sensitive to __________Hz

Table 20.3 Effects of Electrical Shock as a Function of Current[3]

| Current (mA) | Effect |
|---|---|
| 1 | Threshold of sensation |
| 5 | Maximum harmless current |
| 10–20 | Onset of sustained muscular contraction; cannot let go for duration of shock; contraction of chest muscles may stop breathing during shock |
| 50 | Onset of pain |
| 100–300+ | Ventricular fibrillation possible; often fatal |
| 300 | Onset of burns depending on concentration of current |
| 6000 (6 A) | Onset of sustained ventricular contraction and respiratory paralysis; both cease when shock ends; heartbeat may return to normal; used to defibrillate the heart |




## *Homework*

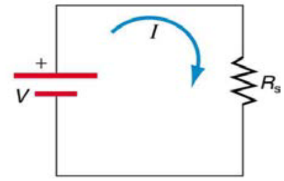
1. What are the two major hazards of electricity?
2. Why isn't a short circuit a shock hazard?
3. What determines the severity of a shock? Can you say that a certain voltage is hazardous without further information?
4. Some devices often used in bathrooms, such as hairdryers, often have safety messages saying "Do not use when the bathtub or basin is full of water." Why is this so?
5. We are often advised to not flick electric switches with wet hands, dry your hand first. We are also advised to never throw water on an electric fire. Why is this so?
6. Before working on a power transmission line, linemen will touch the line with the back of the hand as a final check that the voltage is zero. Why the back of the hand?
7. (a) How much power is dissipated in a short circuit of 240-V AC through a resistance of 0.250 Ω? (b) What current flows? (OpenStax 20.85) **230 kW, 960 A**

8. What voltage is involved in a 1.44-kW short circuit through a 0.100-Ω resistance? (OpenStax 20.86) **12 V**
9. Find the current through a person and identify the likely effect on her if she touches a 120-V AC source: (a) if she is standing on a rubber mat and offers a total resistance of 300 kΩ; (b) if she is standing barefoot on wet grass and has a resistance of only 4500 Ω. (OpenStax 20.87) **0.400 mA (no effect), 26.7 mA (muscular contraction)**
10. While taking a bath, a person touches the metal case of a radio. The path through the person to the drainpipe and ground has a resistance of 4000 Ω. What is the smallest voltage on the case of the radio that could cause ventricular fibrillation? (OpenStax 20.88) **400 V**
11. Foolishly trying to fish a burning piece of bread from a toaster with a metal butter knife, a man comes into contact with 120-V AC. He does not even feel it since, luckily, he is wearing rubber-soled shoes. What is the minimum resistance of the path the current follows through the person? (OpenStax 20.89) $\mathbf{1.20 \times 10^{5}\ \Omega}$
12. (a) During surgery, a current as small as 20.0 μA applied directly to the heart may cause ventricular fibrillation. If the resistance of the exposed heart is 300 Ω, what is the smallest voltage that poses this danger? (b) Does your answer imply that special electrical safety precautions are needed? (OpenStax 20.90) **6.00 mV**
13. (a) What is the resistance of a 220-V AC short circuit that generates a peak power of 96.8 kW? (b) What would the average power be if the voltage was 120 V AC? (OpenStax 20.91) **1.00 Ω, 14.4 kW**
14. A heart defibrillator passes 10.0 A through a patient's torso for 5.00 ms in an attempt to restore normal beating. (a) How much charge passed? (b) What voltage was applied if 500 J of energy was dissipated? (c) What was the path's resistance? (d) Find the temperature increase caused in the 8.00 kg of affected tissue. (OpenStax 20.92) $\mathbf{5.00 \times 10^{-2}}$ **C, 10.0 kV, 1.00 kΩ,** $\mathbf{1.79 \times 10^{-2}}$ **°C**

## *Series Wiring*

- More than ____________ device on ____________
- Same ____________ through ____________ device
- Break in ____________ means ____________ current
- Form one ____________
- The ____________ divide the ____________ between them

$$R_S = R_1 + R_2 + R_3 + \cdots$$




A 5.17 kΩ resistor and a 10.09 kΩ resistor are connected in series. What is the equivalent resistance?

Bathroom vanity lights are often wired in series. V = 120 V and you install 3 bulbs with R = 8 Ω and 1 bulb with R = 12 Ω. What is the current, voltage of each bulb, and the total power used?

## *Parallel Wiring*

- Same ____________ across ____________ devices
- Break in ____________ has no effect on ____________
- Resistors divide ____________
- Each branch draws ____________ as if the other ____________ there
- Each branch draws ____________ current than the ____________ ____________ gives
    - $R = \frac{V}{I}$: Overall circuit: Large I → Small R
    - Smaller ____________ than either ____________

$$\frac{1}{R_P} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \cdots$$

A 1004 Ω resistor and a 101 Ω resistor are connected in parallel. What is the equivalent resistance?

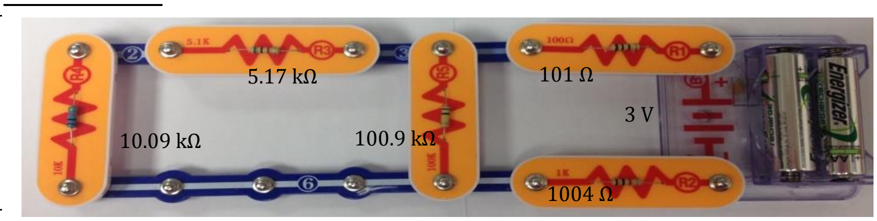
If they were connected to a 3 V battery, how much total current would the battery supply?

How much current through each resistor?

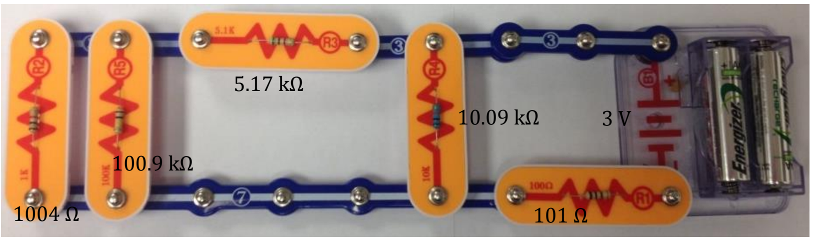
## *Circuits Wired Partially in Series and Partially in Parallel*

1. Simplify any ____________ portions of each ____________
2. Simplify the ____________ circuitry of the ____________
3. If necessary ____________ any remaining ____________

Find the equivalent resistance and the total current of the following circuit.



Find the equivalent resistance.




## *Homework*

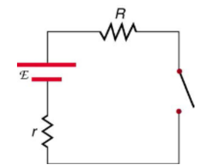



**Figure 1**

1. What is the voltage across the open switch Figure 1?
2. There is a voltage across an open switch, such as in Figure 1. Why, then, is the power dissipated by the open switch small?
3. Why is the power dissipated by a closed switch, such as in Figure 1, small?

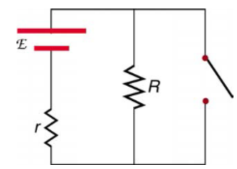



**Figure 2**

4. A student in a physics lab mistakenly wired a light bulb, battery, and switch as shown in Figure 2. Explain why the bulb is on when the switch is open, and off when the switch is closed. (Do not try this–it is hard on the battery!)
5. Some strings of holiday lights are wired in series to save wiring costs. An old version utilized bulbs that break the electrical connection, like an open switch, when they burn out. If one such bulb burns out, what happens to the others? If such a string operates on 120 V and has 40 identical bulbs, what is the normal operating voltage of each? Newer versions use bulbs that short circuit, like a closed switch, when they burn out. If one such bulb burns out, what happens to the others? If such a string operates on 120 V and has 39 remaining identical bulbs, what is then the operating voltage of each?
6. Suppose you are doing a physics lab that asks you to put a resistor into a circuit, but all the resistors supplied have a larger resistance than the requested value. How would you connect the available resistances to attempt to get the smaller value asked for?
7. (a) What is the resistance of ten 275-Ω resistors connected in series? (b) In parallel? (OpenStax 21.1) **2.75 kΩ, 27.5 Ω**
8. (a) What is the resistance of a $1.00 \times 10^{2}$-Ω , a 2.50-kΩ, and a 4.00-k Ω resistor connected in series? (b) In parallel? (OpenStax 21.2) **6.60 kΩ, 93.9 Ω**
9. What are the largest and smallest resistances you can obtain by connecting a 36.0-Ω, a 50.0-Ω, and a 700-Ω resistor together? (OpenStax 21.3) **786 Ω, 20.3 Ω**
10. An 1800-W toaster, a 1400-W electric frying pan, and a 75-W lamp are plugged into the same outlet in a 15-A, 120-V circuit. (The three devices are in parallel when plugged into the same socket.). (a) What current is drawn by each device? (b) Will this combination blow the 15-A fuse? (OpenStax 21.4) **15 A, 11.7 A, 0.63 A, yes**
11. (a) Given a 48.0-V battery and 24.0-Ω and 96.0-Ω resistors, find the current and power for each when connected in series. (b) Repeat when the resistances are in parallel. (OpenStax 21.6) **0.400 A, 3.84 W, 15.4 W; 2.5 A**
12. A 240-kV power transmission line carrying $5.00 \times 10^{2}$ A is hung from grounded metal towers by ceramic insulators, each having a $1.00 \times 10^{9}$-Ω resistance. (a) What is the resistance to ground of 100 of these insulators? (b) Calculate the power dissipated by 100 of them. (c) What fraction of the power carried by the line is this? (OpenStax 21.10) $\mathbf{1.00 \times 10^{7}}$ **Ω,** $\mathbf{5.76 \times 10^{3}}$ **W,** $\mathbf{4.801 \times 10^{-5}}$
13. Two resistors, one having a resistance of 145 Ω, are connected in parallel to produce a total resistance of 150 Ω. (a) What is the value of the second resistance? (b) What is unreasonable about this result? (c) Which assumptions are unreasonable or inconsistent? (OpenStax 21.12) **–4350 Ω**
14. Two resistors, one having a resistance of 900 kΩ, are connected in series to produce a total resistance of 0.500 MΩ. (a) What is the value of the second resistance? (b) What is unreasonable about this result? (c) Which assumptions are unreasonable or inconsistent? (OpenStax 21.13) **–400 kΩ**

## *Emf*

- ________________ ________________
- Not really a ________________
- Really ________________ produced that could ________________ a ________________

## *Internal Resistance*

- ________________ and generators have ________________
  - In batteries → due to ________________
  - In generators → due to ________________ and other ________________
- Internal ________________ is connected in ________________ with the equivalent ________________ of the circuit
- Internal resistance causes ________________ ________________ to drop below ________________
- Internal resistance is not ________________ negligible

$$V = \mathcal{E} - Ir$$

- $V$= terminal voltage, $\mathcal{E}$= emf, $I$= current of circuit, $r$= internal resistance

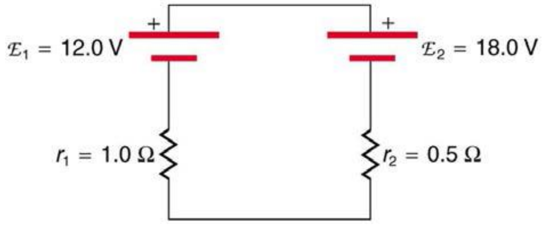
A string of 20 Christmas light are connected in series with a 3.0 V battery. Each light has a resistance of 10 Ω. The terminal voltage is measured as 2.0 V. What is the internal resistance of the battery?

A battery has an internal resistance of 0.02 Ω and an emf of 1.5 V. If the battery is connected with five 15 Ω light bulbs connected in parallel, what is the terminal voltage of the battery?

- If batteries are connected in ________________, their ________________ add, but so do the ________________ ________________
- If batteries are connected in ________________, their ________________ stay the same, but the ________________ add and the combined internal ________________ is ________________

## *Homework*

1. Explain which battery is doing the charging and which is being charged in the figure.




2. Two different 12-V automobile batteries on a store shelf are rated at 600 and 850 "cold cranking amps." Which has the smallest internal resistance?
3. What are the advantages and disadvantages of connecting batteries in series? In parallel?
4. Standard automobile batteries have six lead-acid cells in series, creating a total emf of 12.0 V. What is the emf of an individual lead-acid cell? (OpenStax 21.14) **2.00 V**
5. Carbon-zinc dry cells (sometimes referred to as nonalkaline cells) have an emf of 1.54 V, and they are produced as single cells or in various combinations to form other voltages. (a) How many 1.54-V cells are needed to make the common 9-V battery used in many small electronic devices? (b) What is the actual emf of the approximately 9-V battery? (c) Discuss how internal resistance in the series connection of cells will affect the terminal voltage of this approximately 9-V battery. (OpenStax 21.15) **6, 9.24 V, r's add so smaller V**
6. What is the output voltage of a 3.0000-V lithium cell in a digital wristwatch that draws 0.300 mA, if the cell's internal resistance is 2.00 Ω? (OpenStax 21.16) **2.9994 V**
7. (a) What is the terminal voltage of a large 1.54-V carbon-zinc dry cell used in a physics lab to supply 2.00 A to a circuit, if the cell's internal resistance is 0.100 Ω? (b) How much electrical power does the cell produce? (c) What power goes to its load? (OpenStax 21.17) **1.34 V, 3.08 W, 2.68 W**
8. What is the internal resistance of an automobile battery that has an emf of 12.0 V and a terminal voltage of 15.0 V while a current of 8.00 A is charging it? (OpenStax 21.18) **0.375 Ω**
9. (a) Find the terminal voltage of a 12.0-V motorcycle battery having a 0.600-Ω internal resistance, if it is being charged by a current of 10.0 A. (b) What is the output voltage of the battery charger? (OpenStax 21.19) **18.0 V, 18.0 V**
10. The hot resistance of a flashlight bulb is 2.30 Ω , and it is run by a 1.58-V alkaline cell having a 0.100-Ω internal resistance. (a) What current flows? (b) Calculate the power supplied to the bulb using $I^2R_{bulb}$. (c) Is this power the same as calculated using $\frac{V^2}{R_{bulb}}$? (OpenStax 21.21) **0.658 A, 0.997 W, 0.997 W**
11. An automobile starter motor has an equivalent resistance of 0.0500 Ω and is supplied by a 12.0-V battery with a 0.0100-Ω internal resistance. (a) What is the current to the motor? (b) What voltage is applied to it? (c) What power is supplied to the motor? (d) Repeat these calculations for when the battery connections are corroded and add 0.0900 Ω to the internal resistance. (Significant problems are caused by even small amounts of unwanted resistance in low-voltage, high-current applications.) (OpenStax 21.23) **200 A, 10.0 V, 2.00 kW, 80.0 A, 4.0 V, 320 W**
12. Electric fish generate current with biological cells called electroplaques, which are physiological emf devices. The electroplaques in the South American eel are arranged in 140 rows, each row stretching horizontally along the body and each containing 5000 electroplaques. Each electroplaque has an emf of 0.15 V and internal resistance of 0.25 Ω. If the water surrounding the fish has resistance of 800 Ω, how much current can the eel produce in water from near its head to near its tail? (OpenStax 21.27) **51 A**

# *Kirchhoff's Rules*

## *Junction Rule*

***Total ______________ ______________ a junction must ______________ the total current ______________ of a junction***

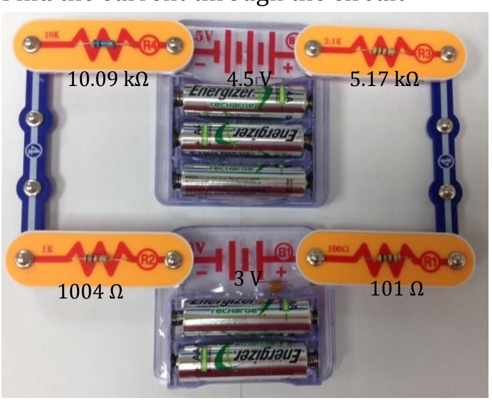
## *Loop Rule*

***For a ______________-circuit loop, the ______________ of all the potential__________ − total of all potential ___________ = 0***
***(or the total voltage of a loop is zero)***

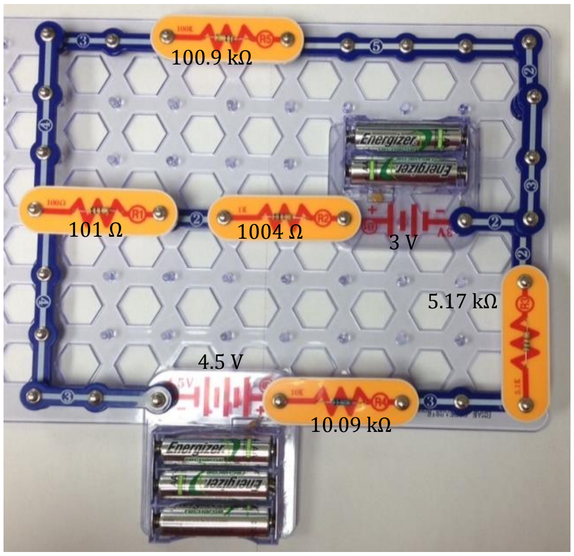
## *Reasoning Strategy*

1. Draw the ______________ in each branch of the circuit (flows out of positive terminal of battery). Choose any ______________. If you are wrong you will get a ______________ current.
2. Mark each ______________ with a ______________ and ______________ signs at opposite ends to show ______________ drop. (Current flows from + to − through a resistor)
3. If the current ______________ the element at +, voltage ______________
4. If the current ______________ the element at −, voltage ______________
5. Apply ____________ rule and ______________ rule to get as many independent ______________ as there are ____________.
6. Solve the ______________ of equations.

Find the current through the circuit



Find the currents through each element.




## *Homework*

1. Can all of the currents going into the junction in Figure 1 be positive? Explain.
2. Apply the junction rule to junction b in Figure 2 Is any new information gained by applying the junction rule at e? (In the figure, each emf is represented by script E.)
3. Apply the loop rule to loop afedcba in Figure 2.
4. Apply the loop rule to loop abcdefgha in Figure 3. (OpenStax 21.31) $\boldsymbol{-I_2R_2 + E_1 - I_2r_1 + I_3R_3 + I_3r_2 - E_2 = 0}$
5. Apply the loop rule to loop aedcba in Figure 3. (OpenStax 21.32) $\boldsymbol{I_1R_1 + I_2r_1 - E_1 + I_2R_2 = 0}$
6. Apply the junction rule at point a in Figure 4. (OpenStax 21.35) $\boldsymbol{I_3 = I_1 + I_2}$
7. Apply the loop rule to loop abcdefghija in Figure 4. (OpenStax 21.36) $\boldsymbol{-I_1R_1 + E_1 - I_1r_1 - I_1R_5 - I_3r_4 - E_4 - I_3r_3 + E_3 - I_3R_3 = 0}$
8. Solve the circuit in Figure 3. Use the loop abcdefgha for one of your equations. (OpenStax 21.38) $\boldsymbol{I_1 = 4.75\ A, I_2 = -3.5\ A, I_3 = 8.25\ A}$

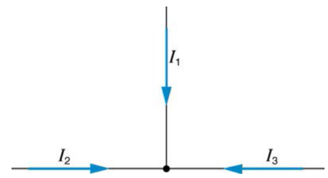



**Figure 1**

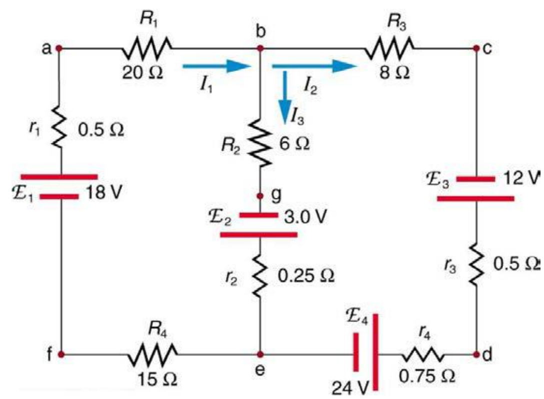



**Figure 2**

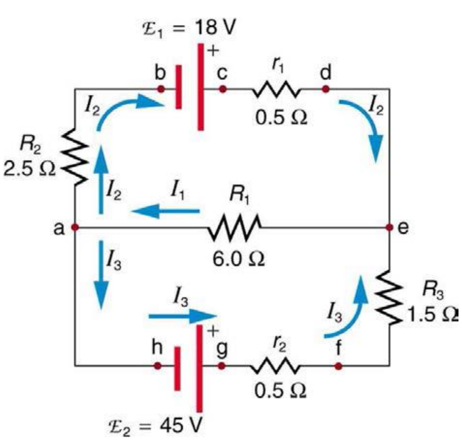



**Figure 3**

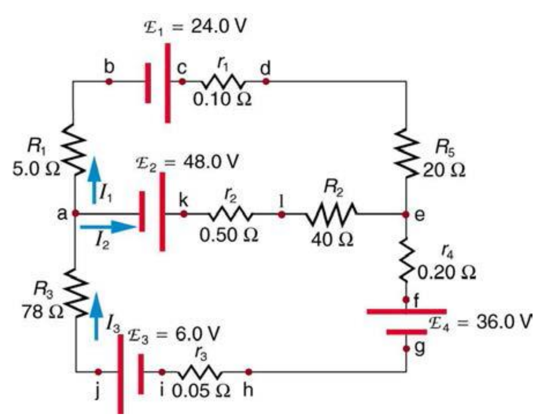
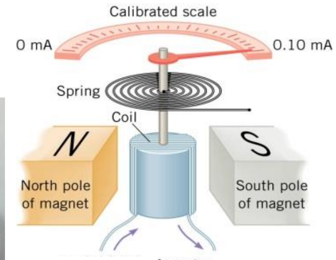



**Figure 4**

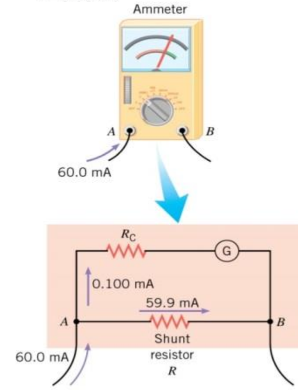
## DC Voltmeters and Ammeters



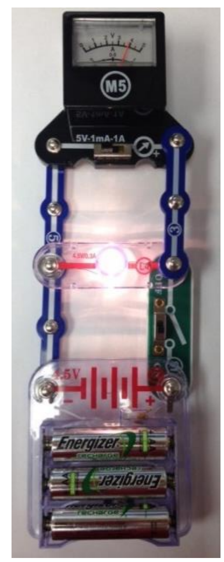

- ____________ (non-digital) meters
- Main component → ____________

## Ammeters

- Measures ____________
- Inserted into ____________ so ____________ passes ____________ it
- Connected in ____________
- Coil usually measures only ____________ current
- Has ____________ ____________ connected in ____________ to galvanometer so excess current can ____________
- A _________ lets you __________ which shunt resistor is _________
- Problems with Ammeters
  - The ____________ of the coil and shunt ____________ add to the ____________ of the circuit
  - This ____________ the ____________ in the circuit
  - ____________ ammeter has ____________ resistance
  - Real-life good ____________ have ____________ resistance so as only cause a ____________ change in current




## Voltmeters



- Connected in ____________ to ____________ since parallel has same ____________
- The coil works just like in the ____________
- Given the ____________ and the ____________ of the coil → ____________
- To give more range, a ____________ resistor is connected in ____________ with the coil
- Problems with Voltmeters
  - The voltmeter takes some the ____________ out of the ____________
  - ____________ voltmeter would have ____________ ____________ resistance as to draw ____________ current
  - Good voltmeter has large ____________ resistance as to make the ____________ draw (and voltage drop) ____________

## Homework

1. Suppose you are using a multimeter (one designed to measure a range of voltages, currents, and resistances) to measure current in a circuit and you inadvertently leave it in a voltmeter mode. What effect will the meter have on the circuit? What would happen if you were measuring voltage but accidentally put the meter in the ammeter mode?
2. Specify the points to which you could connect a voltmeter to measure the following potential differences in Figure 1: (a) the potential difference of the voltage source; (b) the potential difference across $R_1$; (c) across $R_2$; (d) across $R_3$; (e) across $R_2$ and $R_3$. Note that there may be more than one answer to each part.

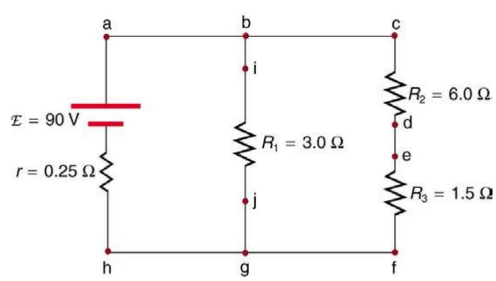
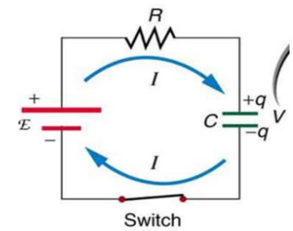



**Figure 1**

3. To measure currents in Figure 1, you would replace a wire between two points with an ammeter. Specify the points between which you would place an ammeter to measure the following: (a) the total current; (b) the current flowing through $R_1$; (c) through $R_2$; (d) through $R_3$. Note that there may be more than one answer to each part.
4. What is the sensitivity of the galvanometer (that is, what current gives a full-scale deflection) inside a voltmeter that has a 1.00-MΩ resistance on its 30.0-V scale? (OpenStax 21.42) **30.0 $\mu$A**

5. What is the sensitivity of the galvanometer (that is, what current gives a full-scale deflection) inside a voltmeter that has a 25.0-k Ω resistance on its 100-V scale? (OpenStax 21.43) **4.00 mA**
6. Find the resistance that must be placed in series with a 25.0-Ω galvanometer having a 50.0-μA sensitivity to allow it to be used as a voltmeter with a 0.100-V full-scale reading. (OpenStax 21.44) **1.98 kΩ**
7. Find the resistance that must be placed in series with a 25.0-Ω galvanometer having a 50.0-μA sensitivity to allow it to be used as a voltmeter with a 3000-V full-scale reading. Include a circuit diagram with your solution. (OpenStax 21.45) $\mathbf{6.00 \times 10^{7}\ \Omega}$
8. Find the resistance that must be placed in parallel with a 25.0-Ω galvanometer having a 50.0-μA sensitivity to allow it to be used as an ammeter with a 10.0-A full-scale reading. Include a circuit diagram with your solution. (OpenStax 21.46) $\mathbf{1.25 \times 10^{-4}\ \Omega}$
9. Find the resistance that must be placed in parallel with a 25.0-Ω galvanometer having a 50.0-μA sensitivity to allow it to be used as an ammeter with a 300-mA full-scale reading. (OpenStax 21.47) $\mathbf{4.17 \times 10^{-3}\ \Omega}$

## *Charging a Capacitor*




- Circuit with a ______________, ______________, and ______________
- Initially capacitor is ______________
- When battery connected current ______________ to charge ______________
- As charges build up, there is ______________ resistance because of the ______________ of the ______________ on the parallel ______________
- When capacitor is ______________ charged, ______________ current will flow

$$q = CV\left(1 - e^{-\frac{t}{RC}}\right)$$

  - $RC = \tau$ (time constant – The time required to charge the capacitor to 63.2%)
  - $CV = Q$ (maximum charge)

$$V = \mathcal{E}\left(1 - e^{-\frac{t}{RC}}\right)$$

  - V is voltage across the capacitor, $\mathcal{E}$ is emf, t is time, R is resistance of circuit, C is capacitance

## *Discharging a Capacitor*

- The battery is ______________
- The ______________ acts like a ______________ supplying ______________ to the circuit

$$q = Qe^{-\frac{t}{RC}}$$
$$V = V_0 e^{-\frac{t}{RC}}$$

- Often capacitors are used to charge ______________, then discharge ______________ like in camera flash.
- Done by have ______________ values for ______________ in charging and discharging.

- Camera flashes work by charging a ______________ with a ______________.
  - Usually has a large time constant because ______________ cannot produce charge very ______________
  - The capacitor is then ______________ through the ______________ circuit with a ______________ time constant

An uncharged capacitor and a resistor are connected in series to a battery. If $V = 12\ V$, $C = 5\ \mu F$, and $R = 8 \times 10^5\ \Omega$. Find the time constant, max charge, max current, and charge as a function of time.

## *Homework*

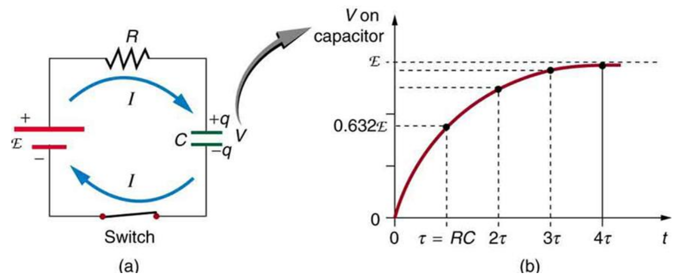



**Figure 1**

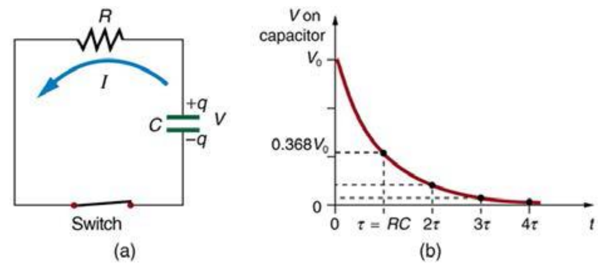



**Figure 2**

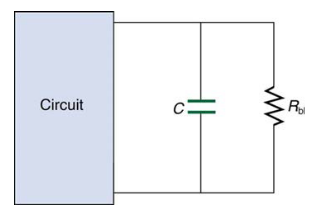



**Figure 3**

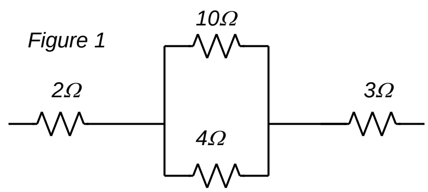
1. Regarding the units involved in the relationship $\tau = RC$, verify that the units of resistance times capacitance are time, that is, $\Omega \cdot F = s$.
2. When making an ECG measurement, it is important to measure voltage variations over small time intervals. The time is limited by the $RC$ constant of the circuit—it is not possible to measure time variations shorter than $RC$. How would you manipulate $R$ and $C$ in the circuit to allow the necessary measurements?
3. When charging a capacitor, as discussed in conjunction with Figure 1, how long does it take for the voltage on the capacitor to reach emf? Is this a problem?
4. When discharging a capacitor, as discussed in conjunction with Figure 2, how long does it take for the voltage on the capacitor to reach zero? Is this a problem?
5. An electronic apparatus may have large capacitors at high voltage in the power supply section, presenting a shock hazard even when the apparatus is switched off. A "bleeder resistor" is therefore placed across such a capacitor, as shown schematically in Figure 3, to bleed the charge from it after the apparatus is off. Why must the bleeder resistance be much greater than the effective resistance of the rest of the circuit? How does this affect the time constant for discharging the capacitor?
6. The timing device in an automobile's intermittent wiper system is based on an RC time constant and utilizes a 0.500-μF capacitor and a variable resistor. Over what range must R be made to vary to achieve time constants from 2.00 to 15.0 s? (OpenStax 21.63) **4.00 to 30.0 MΩ**
7. A heart pacemaker fires 72 times a minute, each time a 25.0-nF capacitor is charged (by a battery in series with a resistor) to 0.632 of its full voltage. What is the value of the resistance? (OpenStax 21.64) $\mathbf{3.33 \times 10^{7}\ \Omega}$
8. The duration of a photographic flash is related to an RC time constant, which is 0.100 μs for a certain camera. (a) If the resistance of the flash lamp is 0.0400 Ω during discharge, what is the size of the capacitor supplying its energy? (b) What is the time constant for charging the capacitor, if the charging resistance is 800 kΩ? (OpenStax 21.65) **2.50 $\mu$F, 2.00 s**
9. A 500-Ω resistor, an uncharged 1.50-μF capacitor, and a 6.16-V emf are connected in series. (a) What is the initial current? (b) What is the RC time constant? (c) What is the current after one time constant? (d) What is the voltage on the capacitor after one time constant? (OpenStax 21.68) **12.3 mA, $\mathbf{7.50 \times 10^{-4}}$ s, 4.53 mA, 3.89 V**
10. An ECG monitor must have an RC time constant less than $1.00 \times 10^{2}$ μs to be able to measure variations in voltage over small time intervals. (a) If the resistance of the circuit (due mostly to that of the patient's chest) is 1.00 kΩ, what is the maximum capacitance of the circuit? (b) Would it be difficult in practice to limit the capacitance to less than the value found in (a)? (OpenStax 21.70) $\mathbf{1.00 \times 10^{-7}}$ **F, No**

# *Physics*

*Unit 9: Electric Circuits*

1. *What is emf, kWh, rms, current, resistance, resistivity, and potential difference?*
2. *How do you use ammeters and voltmeters?*
3. *Know what factors your body's sensitivity to electricity?*
4. *Use Kirchhoff's Laws to solve problems.*
5. *A 2-A current flows through a circuit. How much charge passes a point during 1 minute?*
6. *A flashlight bulb is connected to a 3.0 V battery and a current of .020A flows. What is the resistance of the bulb's filament?*
7. *The resistivity of a metal is $3x10^{-8}$ Ωm. The radius of the wire is 2 mm. If the length of the wire is 3 m, what is the resistance of the wire?*
8. *A 2-A current flows through a circuit with a resistance of 5Ω. How much energy is dissipated in 3 s?*
9. *A 2-A current flows through a circuit that consists of a resistor and an ideal battery. If the battery supplies 400 W, how large is the resistor?*
10. *An AC voltage has a rms value of 5.66. Determine the peak value of the voltage?*
11. *Three resistors, 2-Ω, 3-Ω, 4-Ω, are connected in series. What is the equivalent resistance of the series?*
12. *Two 10-Ω and four 30-Ω light bulbs are connected in series with a 9 V battery. What is the current that passes through each bulb?*
13. *Three resistors, 2-Ω, 3-Ω, 4-Ω, are connected in parallel. What is the equivalent resistance of the combination?*
14. *What is the equivalent resistance of figure 1*

Figure 1




15. *A non-ideal battery has a 12.0 V emf and internal resistance of 4Ω. Determine the terminal voltage of the battery when 2 A is drawn.*
16. *An uncharged 10 F capacitor and a resistor are connected in series to a 9 V battery and an open switch to form a simple RC circuit. The switch is closed at t = 0s. The time constant of the circuit is 30 s. A) How big is the resistor and B)what is the maximum charge on the capacitor?*

5. $I = \frac{q}{t}$
$2A = \frac{q}{60\ s}$
$\boldsymbol{q = 120\ C}$
6. $V = IR$
$3\ V = (0.02\ A)R$
$\boldsymbol{R = 150\ \Omega}$
7. $R = \rho\left(\frac{L}{A}\right)$
$A = \pi r^2 = \pi(0.002\ m)^2 = 1.256 \times 10^{-5}\ m^2$
$R = (3 \times 10^{-8}\ \Omega m)\left(\frac{3\ m}{1.256\times10^{-5}\ m^2}\right) = \boldsymbol{7.16 \times}$
$\boldsymbol{10^{-3}\ \Omega}$
8. $P = I^2R$
$P = (2\ A)^2(5\ \Omega) = 20\ W$
$P = \frac{W}{t}$
$20\ W = \frac{W}{3\ s}$
$\boldsymbol{W = 60\ J}$
9. $P = I^2R$
$400\ W = (2\ A)^2R$
$\boldsymbol{R = 100\ \Omega}$
10. $V_{rms} = \frac{V}{\sqrt{2}}$
$5.66\ V = \frac{V}{\sqrt{2}}$
$\boldsymbol{V = 8.0\ V}$
11. $R_S = R_1 + R_2 + R_3$
$R_S = 2\ \Omega + 3\ \Omega + 4\ \Omega = \boldsymbol{9\ \Omega}$
12. $R_S = R_1 + R_2 + R_3 + R_4 + R_5 + R_6$
$R_S = 2 \cdot (10\ \Omega) + 4 \cdot (30\ \Omega) = 140\ \Omega$
$V = IR$
$9\ V = I(140\ \Omega)$
$\boldsymbol{I = 6.43 \times 10^{-2}\ A}$
13. $\frac{1}{R_P} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$
$\frac{1}{R_P} = \frac{1}{2\ \Omega} + \frac{1}{3\ \Omega} + \frac{1}{4\ \Omega}$
$\frac{1}{R_P} = \frac{6}{12\ \Omega} + \frac{4}{12\ \Omega} + \frac{3}{12\ \Omega} = \frac{13}{12\ \Omega}$
$\boldsymbol{R_P = \frac{12}{13}\ \Omega}$
14. *Combine Parallel (middle)*
$\frac{1}{R_P} = \frac{1}{10\ \Omega} + \frac{1}{4\ \Omega} = \frac{7}{20\ \Omega}$
$R_P = \frac{20}{7}\Omega$
*Combine Series*
$R_S = 2\ \Omega + \frac{20}{7}\ \Omega + 3\ \Omega = \boldsymbol{\frac{55}{7}\ \Omega}$
15. *Internal*
$V = IR = (2\ A)(4\ \Omega) = 8\ V$
*Terminal*
$terminal = emf - internal$
$12\ V - 8\ V = \boldsymbol{4\ V}$
16. a. $\tau = RC$
$30\ s = R(10\ F)$
$\boldsymbol{R = 3\ \Omega}$
b. $Q = CV$
$Q = (9\ V)(10\ F) = \boldsymbol{90\ C}$